A Study of the H-dibaryon in Holographic QCD

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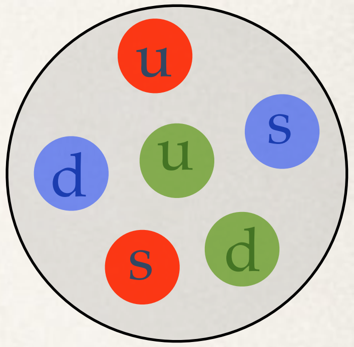
Contents

Introduction

- The aim of this study is to investigate the properties of H-dibaryon in chiral limit using a recent new method of non-perturbative QCD.
- In particular, H-dibaryon mass is interesting from the viewpoint of "existence" of H-dibaryon.

What is H-dibaryon?



- H-dibaryon: B=2 flavor singlet state (uuddss)

  $(J^{\pi} = 0^{+}, I = 0, B = 2, S = \text{-}2, Y = 0)$

  - In 1977, Jaffe first predicted the existence of H-dibaryon in the discussion of color-magnetic interaction by using MIT bag model. [R. L. Jaffe, Phys. Rev. Lett. 38 (1977) 195]
  - In this model, the H-dibaryon mass is $M_H = 2150$ MeV.

    (cf. $\Lambda\Lambda$(2231MeV), $N\Xi$($n\Xi^0$: 2254MeV, $p\Xi^-$: 2260MeV), $\Sigma\Sigma$($\Sigma^0\Sigma^0$: 2385MeV, $\Sigma^+\Sigma^-$: 2387MeV))

    ∴ The H-dibaryon mass may be smaller than the $\Lambda\Lambda$ threshold!

- After that, H-dibaryon mass was also investigated by using Skyrme model, and the result is: [A. P. Balachandran et al., Nucl. Phys. B256 (1985) 525] [R. L. Jaffe et al., Nucl. Phys. B258 (1985) 468]

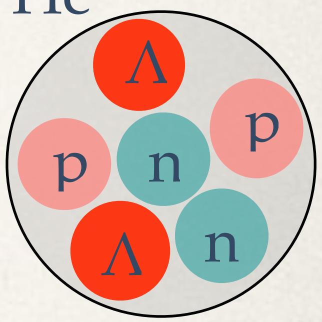
  $$M_H \simeq 1.92 M_{B=1} (< 2M_{B=1}) \quad \text{(in chiral limit)}$$

  - This result seems to support Jaffe's prediction.

Experimental Status

- However, the prediction of the low-mass H-dibaryon is denied experimentally in 1991 (at physical point):
  - Instead, the double hyper nuclei ${}_{\Lambda\Lambda}{}^{6}\mathrm{He}$ was found by Imai group.
    [K. Imai, Nucl. Phys. A527, 181(1991)]
    [H. Takahashi et al., Phys. Rev. Lett. 87, 212502(2001)]
  - In fact, H-dibaryon is not a stable state, that is, there is no-deeply-bound H particle at least at the physical point.

${}_{\Lambda\Lambda}{}^{6}\mathrm{He}$



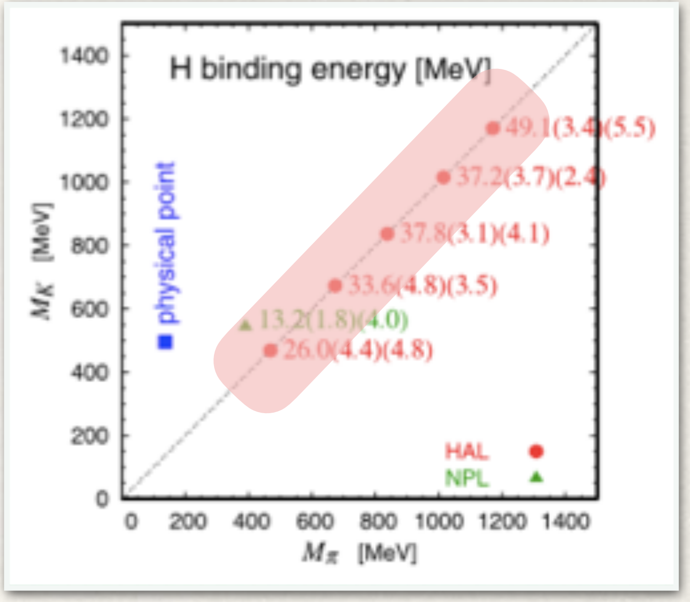
- Why Jaffe failed?
  - A possible reason is a large SU(3) flavor symmetry breaking due to large s-quark mass ($m_s \gg m_{u,d}$).
- Then, current interests of H-dibaryon are:
  - H-dibaryon may exist as a resonance at physical point.
  - How is the stability of H at unphysical points such as flavor SU(3) symmetric case ($m_u=m_d=m_s$) ?

Lattice QCD Studies of H-dibaryon

- As a resent progress, Lattice QCD calculation indicates the existence of H-dibaryon at "unphysical points":

  [NPLQCD (S. Beane et al.), Phys. Rev. Lett. 106 (2011)162001]
  [HAL QCD (T. Inoue et al.), Phys. Rev. Lett. 106 (2011) 162002]
  [HAL QCD (T. Inoue et al.), Nucl. Phys. A881, 28 (2012)]

  - H is stable at the flavor SU(3) symmetric ($m_u=m_d=m_s$) and large quark-mass region.



- Then, how about in chiral limit?
  - Lattice QCD calculation is usually a powerful tool to evaluate hadron masses, but it is difficult to take the chiral limit. (large-size box is required)
- For the study of the chiral limit, some model approach such as Skyrme model would be useful instead of lattice QCD.
  - It is desirable to use some QCD-based model for the calculation.

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Skyrme Model

- Skyrme model [T. H. R. Skyrme, Nucl. Phys. 31 (1962) 556]

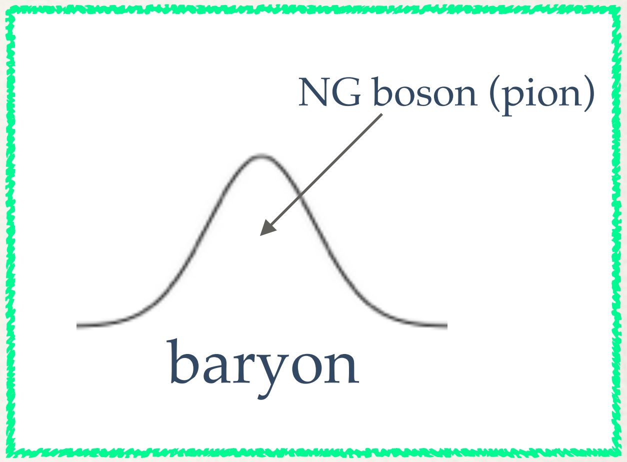
$$\mathcal{L} = \frac{f_\pi^2}{4}\mathrm{tr}(L_\mu L^\mu) + \frac{1}{32e^2}\mathrm{tr}[L_\mu, L_\nu]^2$$ (+ WZW term)

kinetic term

"Skyrme term" (introduced by hand)

$$L_\mu \equiv \frac{1}{i}U^\dagger \partial_\mu U$$

chiral field: $U(x) = e^{i\pi(x)/f_\pi} \in SU(N_f)$



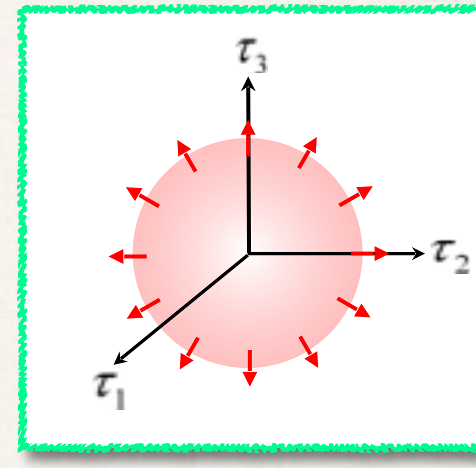
- This is the first theory of chiral solitons which describe baryons in terms of pions.
- This picture is qualitatively supported in the large N_c argument (by E.Witten,1979).

- The soliton solution of this model is called "Skyrmion".
  To investigate Skyrmions, hedgehog Ansatz is usually used.

Skyrme Model in B=1 SU(2) Flavor Case

<u>Hedgehog Ansatz</u>

$N_f = 2$ case (ud flavor)
for B=1 particle (Nucleon)
[T. H. R. Skyrme, Nucl. Phys. 31 (1962) 556]



hedgehog Ansatz

- SU(2) hedgehog Ansatz:

$$U(\mathbf{x}) = e^{i(\tau\cdot\hat{\mathbf{x}})F(r)} \in \mathrm{SU}(2)$$

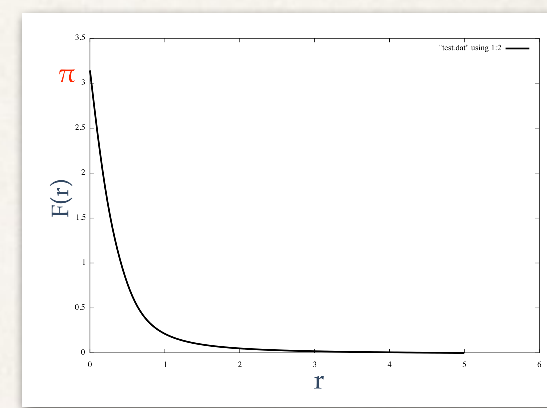
It has one function F(r)   ($\tau_{i=1,2,3}$: Pauli matrices)

$\Rightarrow$ #baryon = $n \in \mathbb{Z}$

- B = 1 Skyrmion ← with — boundary condition
  in SU(2) flavor case
  corresponds to nucleon.

<u>boundary condition</u>

$$\begin{cases} F(0) = \pi \\ F(\infty) = 0 \end{cases}$$



- The B=2 Skyrmion corresponding to H-dibaryon can be obtained by using hedgehog Ansatz of SO(3) subalgebra of SU(3) flavor, instead of SU(2) flavor.

Skyrme Model for H-dibaryon as SO(3) soliton

Hedgehog Ansatz $N_f = 3$ case (uds flavor)

SU(3) ⊃ SU(2), SO(3)

[A. P. Balachandran et al., Nucl. Phys. B256 (1985) 525]
[R. L. Jaffe et al., Nucl. Phys. B258 (1985) 468]

- SO(3) subalgebra:

$$\Lambda_1 = \lambda_7 = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & -i \\ 0 & i & 0 \end{pmatrix} \quad \Lambda_2 = -\lambda_5 = \begin{pmatrix} 0 & 0 & i \\ 0 & 0 & 0 \\ -i & 0 & 0 \end{pmatrix} \quad \Lambda_3 = \lambda_2 = \begin{pmatrix} 0 & -i & 0 \\ i & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

$$[\Lambda_i, \Lambda_j] = i\epsilon_{ijk}\Lambda_k$$

symmetric for flavor (u, d, s)

- SO(3) hedgehog Ansatz:

$$U(\mathbf{x}) = e^{i[(\mathbf{\Lambda}\cdot\hat{\mathbf{x}})F(r)+((\mathbf{\Lambda}\cdot\hat{\mathbf{x}})^2-2/3)\varphi(r)]} \in SU(3)$$

It has 2 functions F(r), ϕ(r)

⇒ #baryon = 4n or 4n+2 ($n \in \mathbb{Z}$)

- B = 2 ⇒ dibaryon (stable) ← with

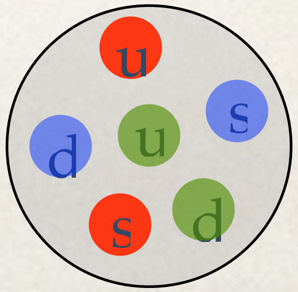
boundary condition

$\cos F(\infty) = 1$ $\cos F(0) = -1$

$e^{i\varphi(\infty)/3} = 1$ $e^{i\varphi(0)/3} = -e^{i2\pi k/3}$

$G(\infty) = 0$ $G(0) = 0$

We can obtain stable dibaryon as Skyrmion by using "SO(3)" hedgehog Ansatz.



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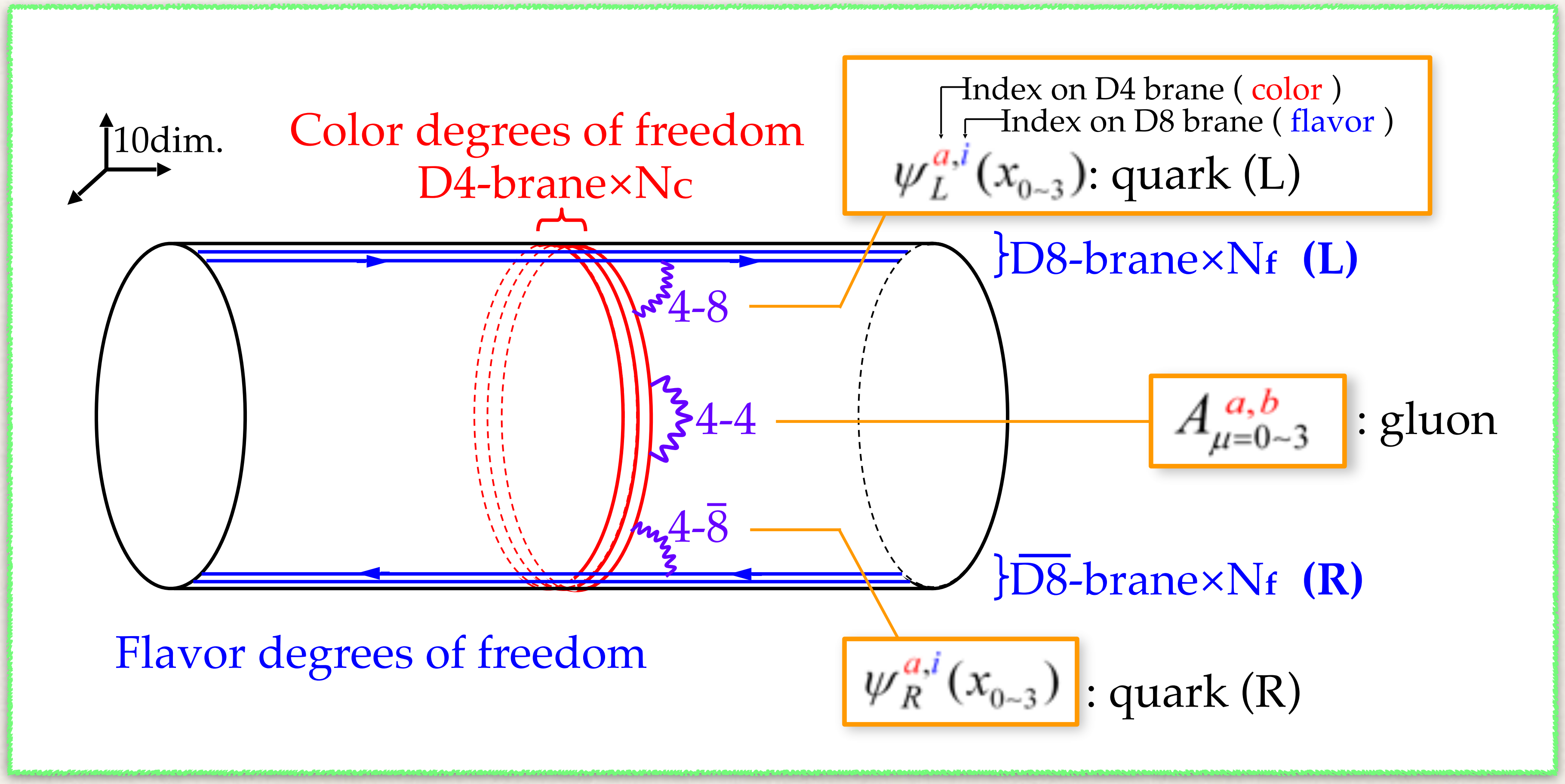
Holographic QCD

<u>Sakai-Sugimoto Model</u>

[T. Sakai and S. Sugimoto, Prog. Theor. Phys. 113 (2005) 843.]

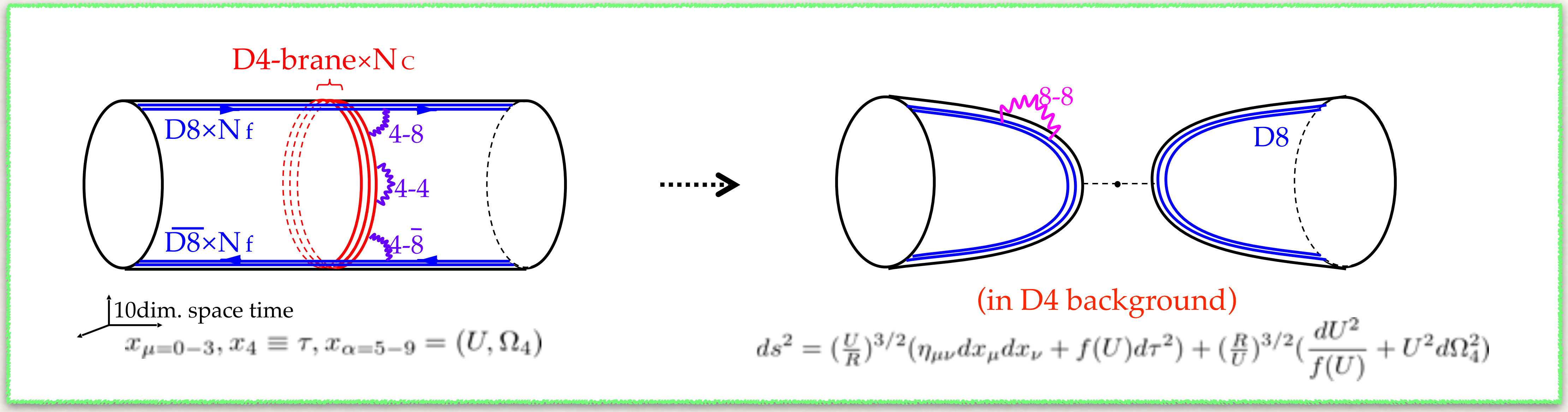
- QCD-equivalent D-brane system (D4/D8/$\overline{\text{D8}}$) can be constructed in superstring theory.



Holographic QCD [T. Sakai and S. Sugimoto, Prog. Theor. Phys. 113 (2005) 843.]

Large N_c limit

In large N_c limit, N_c D4-branes are extremely massive
⇒ replaced by gravitational background



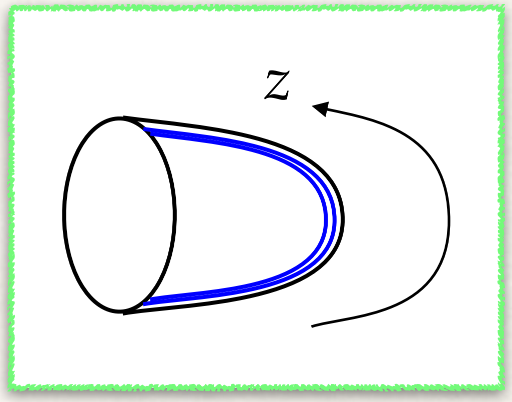
⇒ N_f D8-branes are treated as "probes" in the SUGRA background solution of N_c D4-branes in large N_c limit.

Note: For the reliability of SUGRA description, large 't Hooft coupling ($\lambda \equiv g_{YM}^2 N_c$) is also needed. (g_{YM}: coupling const. of gauge theory)

Holographic QCD [T. Sakai and S. Sugimoto, Prog. Theor. Phys. 113 (2005) 843.]

DBI action of D8-brane

- In large N_c (& large λ) limit, probe D8-brane can be express by the Dirac-Born-Infeld action: ($M_{KK} = 1$ unit)



$$S_{\rm D8}^{\rm DBI} = T_8 \int d^9x e^{-\phi}\sqrt{-\det(g_{MN} + 2\pi\alpha' F_{MN})}$$

integrate over S^4 (degree of freedom of spherical coordinate of $x_{5\text{-}9}$) and expand in terms of $\alpha' F_{\mu\nu}$ (field strength on D8-brane) according to $1/N_c$, $1/\lambda$

$$S_{\rm HQCD} \sim \kappa \int d^4x dz \,{\rm tr}\left(\frac{1}{2}K(z)^{-1/3}F_{\mu\nu}F_{\mu\nu} + K(z)F_{\mu z}F_{\mu z}\right) + O(F^4) \qquad \text{(Euclid. metric)}$$

"5-dimensional Effective action of D8-brane"

$F_{MN} = \partial_M A_N - \partial_N A_M + i[A_M, A_N]$ (M, N = 0-3, z)
$K(z) \equiv 1 + z^2$; $\kappa = \lambda N_c/108\pi^3$
T_8: surface tension of D8-brane / $\alpha' \equiv l_s^2$

note: the gravitational energy is abbreviated above

- Furthermore, the 4-dimensional meson effective theory can be derived by performing mode expansion of gauge field $A_{\mu=0\text{-}3}(x_\nu, z)$ along z-direction.

Holographic QCD [T. Sakai and S. Sugimoto, Prog. Theor. Phys. 113 (2005) 843.]

Construction of 4D Meson Effective Theory

- First, we take $A_z = 0$ gauge in the 5D effective action S_{HQCD}.
- Next, we perform mode expansion of $A_\mu(x_\nu, z)$ in z-direction:

$$A_\mu(x_\nu, z) = l_\mu(x_\nu)\psi_+(z) + r_\mu(x_\nu)\psi_-(z) + \sum_{n\geq 1} B_\mu^{(n)}(x_\nu)\psi_n(z)$$

left/right current by pion (axial) vector meson

proper orthogonal basis

$\{\psi_\pm(z), \psi_n(z)(n = 1, 2, \dots)\}$

$$\psi_\pm(z) \equiv \frac{1}{2} \pm \hat{\psi}_0(z)$$

$$\hat{\psi}_0(z) \equiv \frac{1}{\pi} \arctan z$$

$$-K(z)^{1/3}\frac{d}{dz}[K(z)\frac{d\psi_n}{dz}] = \lambda_n \psi_n$$

pion (NG mode) $\left\{ \; l_\mu(x_\nu) \equiv \frac{1}{i}\xi_+(x_\nu)\partial_\mu\xi_+^{-1}(x_\nu) \quad r_\mu(x_\nu) \equiv \frac{1}{i}\xi_-(x_\nu)\partial_\mu\xi_-^{-1}(x_\nu) \quad \xi_\pm(x_\mu) \in U(N_f) \right.$

- Chiral Field: $U(x_\mu) = e^{i\pi(x_\mu)/f_\pi} = \xi_+^{-1}(x_\mu)\xi_-(x_\mu) \in U(N_f)$
- Vector Meson Field: $B_\mu^{(n)} = B_\mu^{a(n)} T_a$

- For the construction of low-energy QCD effective theory, here we consider NG bosons and the lightest vector meson, only "ρ-meson": [K. Nawa, H. Suganuma, T. Kojo, Phys. Rev. D75, 086003 (2007)]

$$A_\mu(x_\nu, z) \simeq l_\mu(x_\nu)\psi_+(z) + r_\mu(x_\nu)\psi_-(z) + \rho_\mu(x_\nu)\psi_1(z)$$

Holographic QCD

[T. Sakai and S. Sugimoto, Prog. Theor. Phys. 113 (2005) 843.]
[K. Nawa, H. Suganuma, T. Kojo, Phys. Rev. D75, 086003 (2007)]

Construction of Meson Effective Theory

- By the mode expansion of $A_\mu(x_\nu, z)$, we can derive the 4D meson effective theory in terms of pion & vector meson fields from holographic QCD:

$$A_\mu(x_\nu, z) \simeq l_\mu(x_\nu)\psi_+(z) + r_\mu(x_\nu)\psi_-(z) + \rho_\mu(x_\nu)\psi_1(z)$$

substitute

axial vector current: $\alpha_\mu(x_\nu) \equiv l_\mu(x_\nu) - r_\mu(x_\nu)$

vector current: $\beta_\mu(x_\nu) \equiv \frac{1}{2}\{l_\mu(x_\nu) + r_\mu(x_\nu)\}$

$$\begin{aligned}
S_{\rm HQCD} &= \kappa \int d^4x dz \,\mathrm{tr}\left\{\frac{1}{2}K(z)^{-\frac{1}{3}}F_{\mu\nu}F_{\mu\nu} + K(z)F_{\mu z}F_{\mu z}\right\} \\
&= \frac{f_\pi^2}{4}\int d^4x \,\mathrm{tr}\,(L_\mu L_\mu) && \text{(chiral term)} \\
&+ \frac{1}{2}\frac{1}{16e^2}[i^2]\int d^4x \,\mathrm{tr}\,[L_\mu, L_\nu]^2 && \text{(Skyrme term)} \\
&+ \frac{1}{2}\int d^4x \,\mathrm{tr}\,(\partial_\mu\rho_\nu - \partial_\nu\rho_\mu)^2 && \text{(ρ-kinetic term)} \\
&+ m_\rho^2 \int d^4x \,\mathrm{tr}\,(\rho_\mu\rho_\mu) && \text{(ρ-mass term)} \\
&+ \frac{1}{2}2g_{3\rho}[-i]\int d^4x \,\mathrm{tr}\,\{(\partial_\mu\rho_\nu - \partial_\nu\rho_\mu)[\rho_\mu, \rho_\nu]\} && \text{(3ρ coupling)} \\
&+ \frac{1}{2}g_{4\rho}[(-i)^2]\int d^4x \,\mathrm{tr}\,[\rho_\mu, \rho_\nu]^2 && \text{(4ρ coupling)} \\
&+ i\, g_1 \int d^4x \,\mathrm{tr}\,\{[\alpha_\mu, \alpha_\nu](\partial_\mu\rho_\nu - \partial_\nu\rho_\mu)\} && \text{($\partial\rho$-2α coupling)} \\
&+ g_2 \int d^4x \,\mathrm{tr}\,\{[\alpha_\mu, \alpha_\nu][\rho_\mu, \rho_\nu]\} && \text{(2ρ-2α coupling)} \\
&+ g_3 \int d^4x \,\mathrm{tr}\,\{[\alpha_\mu, \alpha_\nu]([\beta_\mu, \rho_\nu] + [\rho_\mu, \beta_\nu])\} && \text{(ρ-2α-β coupling)} \\
&- i\, g_4 \int d^4x \,\mathrm{tr}\,\{(\partial_\mu\rho_\nu - \partial_\nu\rho_\mu)([\beta_\mu, \rho_\nu] + [\rho_\mu, \beta_\nu])\} && \text{(ρ-$\partial\rho$-β coupling)} \\
&- g_5 \int d^4x \,\mathrm{tr}\,\{[\rho_\mu, \rho_\nu]([\beta_\mu, \rho_\nu] + [\rho_\mu, \beta_\nu])\} && \text{(3ρ-β coupling)} \\
&- \frac{1}{2} g_6 \int d^4x \,\mathrm{tr}\,([\alpha_\mu, \rho_\nu] + [\rho_\mu, \alpha_\nu])^2 && \text{(2ρ-2α coupling)} \\
&- \frac{1}{2} g_7 \int d^4x \,\mathrm{tr}\,([\beta_\mu, \rho_\nu] + [\rho_\mu, \beta_\nu])^2 && \text{(2ρ-2β coupling).}
\end{aligned}$$

- Here we can see:
  - this theory has just two parameters (M_{KK} & κ) such as f_π, m_ρ.
    (other coupling constants depend only on M_{KK} & κ.)
  - this effective theory is "derived" from QCD, so it is considered as QCD-based model.

H-dibaryon in Holographic QCD

The Soliton Solution of the Meson Effective Theory S_{HQCD}

- The B=1 SU(2) case has been investigated: [K. Nawa, H. Suganuma, T. Kojo, Phys. Rev. D75, 086003 (2007)]

- Here we consider the SU(3) flavor case to describe H-dibaryon in the chiral limit in holographic QCD for the first time.

  [A. P. Balachandran et al., Nucl. Phys. B256 (1985) 525]
  [R. L. Jaffe et al., Nucl. Phys. B258 (1985) 468]

- We study H-dibaryon in holographic QCD in the following manner:
  - Action (Euclid. metric)

    $$S_{\rm HQCD} = \int d^4x \{ \frac{f_\pi^2}{4}{\rm tr}(L_\mu L_\mu) - \frac{1}{32e^2}{\rm tr}[L_\mu, L_\nu]^2 \} + \frac{1}{2}{\rm tr}(\partial_\mu \rho_\nu - \partial_\nu \rho_\mu)^2 + m_\rho^2 {\rm tr}(\rho_\mu \rho_\mu) + (\text{int. term}) \}$$

  - Meson Field ☞ "SO(3)" Hedgehog Ansatz ($N_f = 3$)
    - Chiral Field: $U(\mathbf{x}) = e^{i[(\mathbf{\Lambda}\cdot\hat{\mathbf{x}})F(r) + ((\mathbf{\Lambda}\cdot\hat{\mathbf{x}})^2 - 2/3)\varphi(r)]} \in SU(3)$
    - lowest SO(3) vector-meson field "ρ-meson": $\rho_0(\mathbf{x}) = 0\,, \rho_i(\mathbf{x}) = \{\epsilon_{ijk}\hat{x}_j G(r)\}\Lambda_k$

      "Wu-Yang-'t Hooft-Polyakov Ansatz"

⇒ Energy (static soliton mass): $E[F(r), \varphi(r), G(r)] \equiv S_{\rm HQCD}|_{\rm hedgehog}$

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Effective Action on SU(3) Flavor

We derive the effective action for H-dibaryon as SO(3)-type hedgehog soliton in terms of profile functions $F(r)$, $\varphi(r)$, $G(r)$ from holographic QCD (Euclid. metric).

$$
\begin{aligned}
S_{\rm HQCD} &= \kappa \int d^4x dz \, {\rm tr} \left\{ \frac{1}{2} K(z)^{-\frac{1}{3}} F_{\mu\nu} F_{\mu\nu} + K(z) F_{\mu z} F_{\mu z} \right\} \\
&= \frac{f_\pi^2}{4} \int d^4x \, {\rm tr}\,(L_\mu L_\mu) \quad \text{(chiral term)} \\
&+ \frac{1}{2} \frac{1}{16 e^2} [i^2] \int d^4x \, {\rm tr}\,[L_\mu, L_\nu]^2 \quad \text{(Skyrme term)} \\
&+ \frac{1}{2} \int d^4x \, {\rm tr}\,(\partial_\mu \rho_\nu - \partial_\nu \rho_\mu)^2 \quad \text{(ρ-kinetic term)} \\
&+ m_\rho^2 \int d^4x \, {\rm tr}\,(\rho_\mu \rho_\mu) \quad \text{(ρ-mass term)} \\
&+ \frac{1}{2} 2 g_{3\rho} [-i] \int d^4x \, {\rm tr}\,\{(\partial_\mu \rho_\nu - \partial_\nu \rho_\mu)[\rho_\mu, \rho_\nu]\} \quad \text{(3ρ coupling)} \\
&+ \frac{1}{2} g_{4\rho} [(-i)^2] \int d^4x \, {\rm tr}\,[\rho_\mu, \rho_\nu]^2 \quad \text{(4ρ coupling)} \\
&+ i\, g_1 \int d^4x \, {\rm tr}\,\{[\alpha_\mu, \alpha_\nu](\partial_\mu \rho_\nu - \partial_\nu \rho_\mu)\} \quad \text{($\partial\rho$-2α coupling)} \\
&+ g_2 \int d^4x \, {\rm tr}\,\{[\alpha_\mu, \alpha_\nu][\rho_\mu, \rho_\nu]\} \quad \text{(2ρ-2α coupling)} \\
&+ g_3 \int d^4x \, {\rm tr}\,\{[\alpha_\mu, \alpha_\nu]([\beta_\mu, \rho_\nu] + [\rho_\mu, \beta_\nu])\} \quad \text{(ρ-2α-β coupling)} \\
&- i\, g_4 \int d^4x \, {\rm tr}\,\{(\partial_\mu \rho_\nu - \partial_\nu \rho_\mu)([\beta_\mu, \rho_\nu] + [\rho_\mu, \beta_\nu])\} \quad \text{(ρ-$\partial\rho$-β coupling)} \\
&- g_5 \int d^4x \, {\rm tr}\,\{[\rho_\mu, \rho_\nu]([\beta_\mu, \rho_\nu] + [\rho_\mu, \beta_\nu])\} \quad \text{(3ρ-β coupling)} \\
&- \tfrac{1}{2} g_6 \int d^4x \, {\rm tr}\,([\alpha_\mu, \rho_\nu] + [\rho_\mu, \alpha_\nu])^2 \quad \text{(2ρ-2α coupling)} \\
&- \tfrac{1}{2} g_7 \int d^4x \, {\rm tr}\,([\beta_\mu, \rho_\nu] + [\rho_\mu, \beta_\nu])^2 \quad \text{(2ρ-2β coupling).}
\end{aligned}
$$

Substituting SO(3) hedgehog Ansatz,

$$
\begin{aligned}
U(\mathbf{x}) &= e^{i[(\mathbf{\Lambda}\cdot\hat{\mathbf{x}})F(r) + ((\mathbf{\Lambda}\cdot\hat{\mathbf{x}})^2 - 2/3)\varphi(r)]} \\
\rho_0(\mathbf{x}) &= 0 \\
\rho_i(\mathbf{x}) &= \{\epsilon_{ijk} \hat{x}_j G(r)\} \Lambda_k
\end{aligned}
$$

and after some calculation, we derive the effective theory of H-dibaryon.

Effective Action on SU(3) Flavor

We derive the effective action for H-dibaryon as SO(3)-type hedgehog soliton in terms of profile functions $F(r)$, $\varphi(r)$, $G(r)$ from holographic QCD as follows:

$$S_{\mathrm{HQCD}} \sim \kappa \int d^4x dz \mathrm{tr}(\frac{1}{2}K(z)^{-1/3}F_{\mu\nu}F_{\mu\nu} + K(z)F_{\mu z}F_{\mu z}) + O(F^4)$$

$$\sim \int d^4x \{ \frac{f_\pi^2}{4}[2F'^2 + \frac{2}{3}\varphi'^2 + \frac{8}{r^2}(1-\cos F\cos\varphi)]$$ (chiral term)

$$+\frac{1}{32e^2}\frac{16}{r^2}[(\varphi'^2 + F'^2)(1-\cos F\cos\varphi) + 2\varphi' F'\sin F\sin\varphi$$
$$+\frac{1}{r^2}\{(1-\cos F\cos\varphi)^2 + 3\sin^2 F\sin^2\varphi\}]$$ (Skyrme term)

$$+\frac{1}{2}[8(\frac{3}{r^2}G^2 + \frac{2}{r}GG' + G'^2)] + m_\rho^2[4G^2]$$ (ρ-kinetic term / ρ-mass term)

$$+g_{3\rho}[8\frac{G^3}{r}] + \frac{1}{2}g_{4\rho}[4G^4]$$ (3ρ coupling / 4ρ coupling)

$$-g_1[\frac{16}{r}\{(\frac{1}{r}G + G')(F'\sin\frac{F}{2}\cos\frac{\varphi}{2} + \varphi'\cos\frac{F}{2}\sin\frac{\varphi}{2}) + \frac{1}{r^2}G(1-\cos F\cos\varphi)\}]$$ (∂ρ-2α coupling)

$$-g_2[\frac{8}{r^2}G^2(1-\cos F\cos\varphi)]$$ (2ρ-2α coupling)

$$+g_3[\frac{16}{r^3}G\{3\sin F\sin\frac{F}{2}\sin\varphi\sin\frac{\varphi}{2} + (1-\cos\frac{F}{2}\cos\frac{\varphi}{2})(1-\cos F\cos\varphi)\}]$$ (ρ-2α-β coupling)

$$-g_4[\frac{16}{r^2}G^2(1-\cos\frac{F}{2}\cos\frac{\varphi}{2})]$$ (ρ-∂ρ-β coupling)

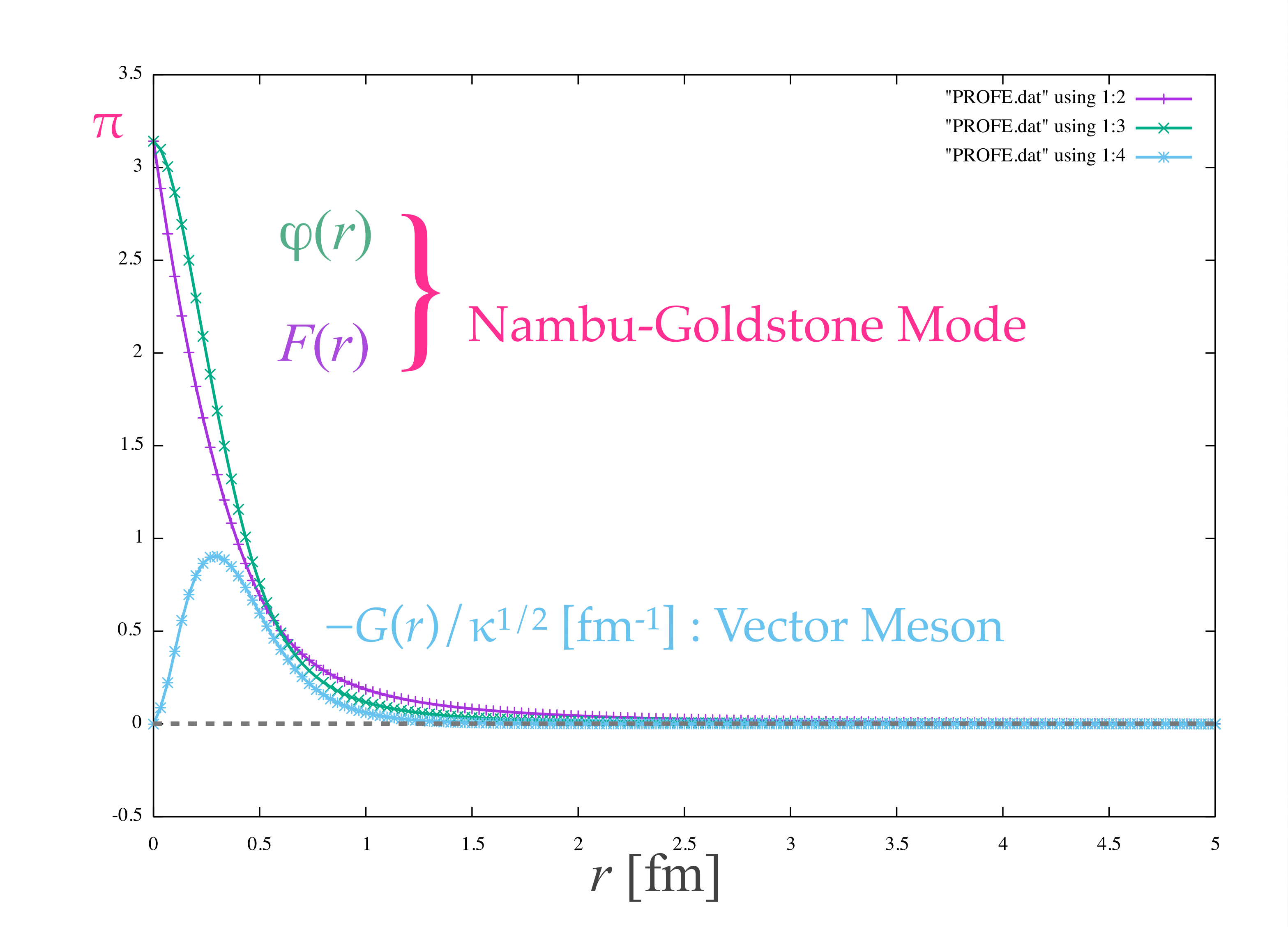
$$-g_5[\frac{8}{r}G^3(1-\cos\frac{F}{2}\cos\frac{\varphi}{2})]$$ (3ρ-β coupling)

$$+g_6[4G^2(F'^2 + \varphi'^2)]$$ (2ρ-2α coupling)

$$+g_7[\frac{8}{r^2}G^2\{3\sin^2\frac{F}{2}\sin^2\frac{\varphi}{2} + (1-\cos\frac{F}{2}\cos\frac{\varphi}{2})^2\}] \}$$ (2ρ-2β coupling)

Numerical Results

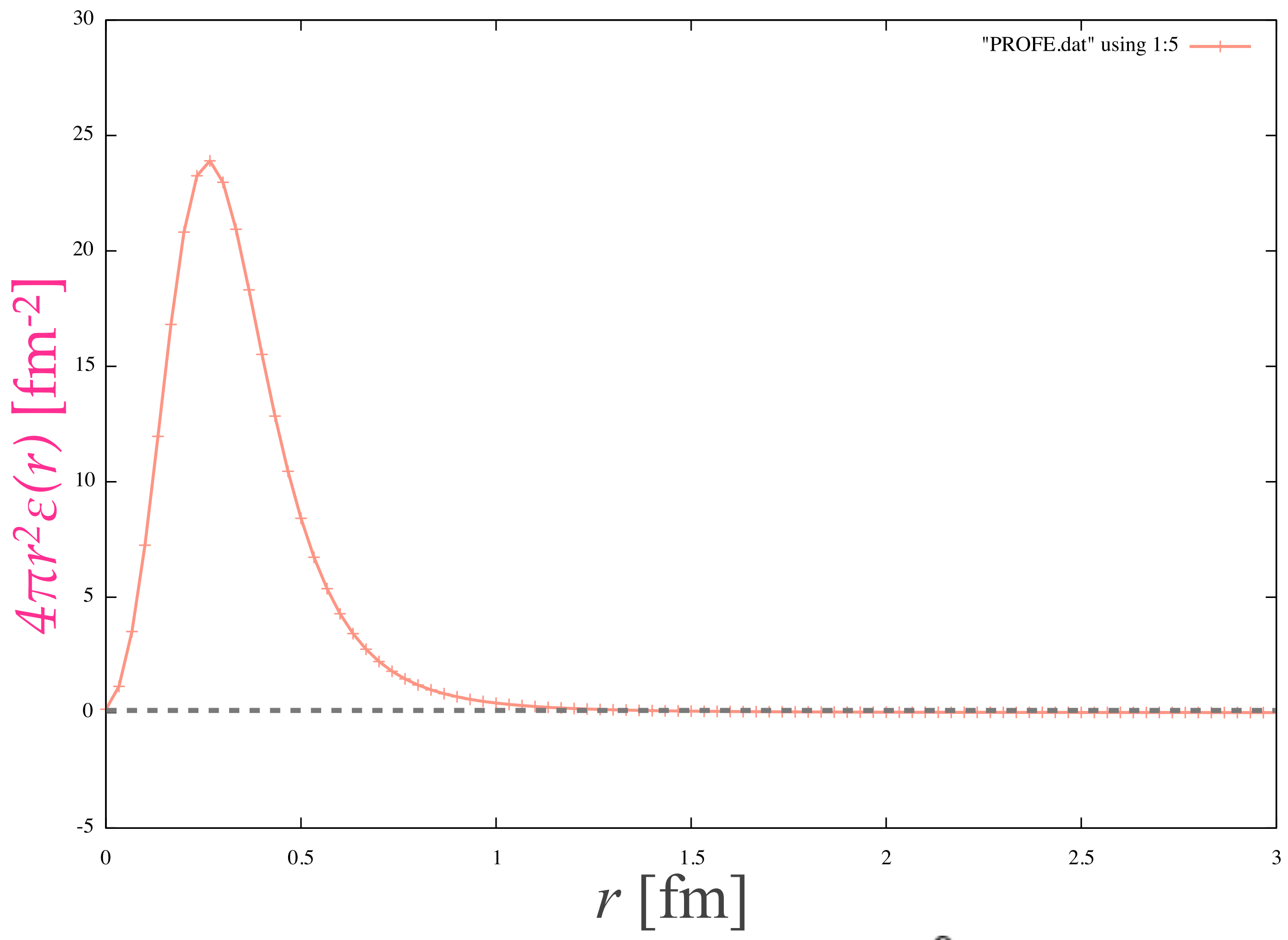
Profile functions of H-dibaryon



- SO(3) hedgehog soliton solution exists in this framework.
- This soliton solution corresponds to H-dibaryon in chiral limit.

Numerical Results

Energy density of H-dibaryon



$$E[F(r), \varphi(r), G(r)] = 4\pi \int dr r^2 \varepsilon(r)$$

- By using the energy density, the radius of H-dibaryon can be calculated:

$$< r^2 >= \frac{\int dr r^2 \cdot r^2 \varepsilon(r)}{\int dr r^2 \varepsilon(r)}$$

(mean square radius)

Numerical Results

Mass & Radius of H-diaryon

- Holographic QCD has just two parameters:
  - M_{KK}: energy scale of the theory
  - κ : large-N_c effective theory
- We determine these two parameters to reproduce pion decay constant and ρ-meson mass:

$$f_\pi = 92.4 \text{ MeV}\,, \quad m_\rho = 776.0 \text{ MeV}$$

- Then, the mass and radius of H-dibaryon (in chiral limit) are:

$$\text{Mass: } M_{\mathrm{H}} \simeq 1673 \text{ MeV}\,, \;\; \text{Radius: } \sqrt{\langle r^2 \rangle} \simeq 0.413 \text{ fm}$$

Comparison to B=1 Soliton Results

Mass: $M_{\rm H} \simeq 1673$ MeV , Radius: $\sqrt{\langle r^2 \rangle} \simeq 0.413$ fm

- The mass and radius of B=1 hedgehog baryon in holographic QCD (in chiral limit) are $M_{\rm B=1} \simeq 834.0 {\rm MeV}$, $\sqrt{\langle r^2 \rangle} \simeq 0.37 {\rm fm}$

[K. Nawa, H. Suganuma, T. Kojo, Phys. Rev. D75, 086003 (2007)]

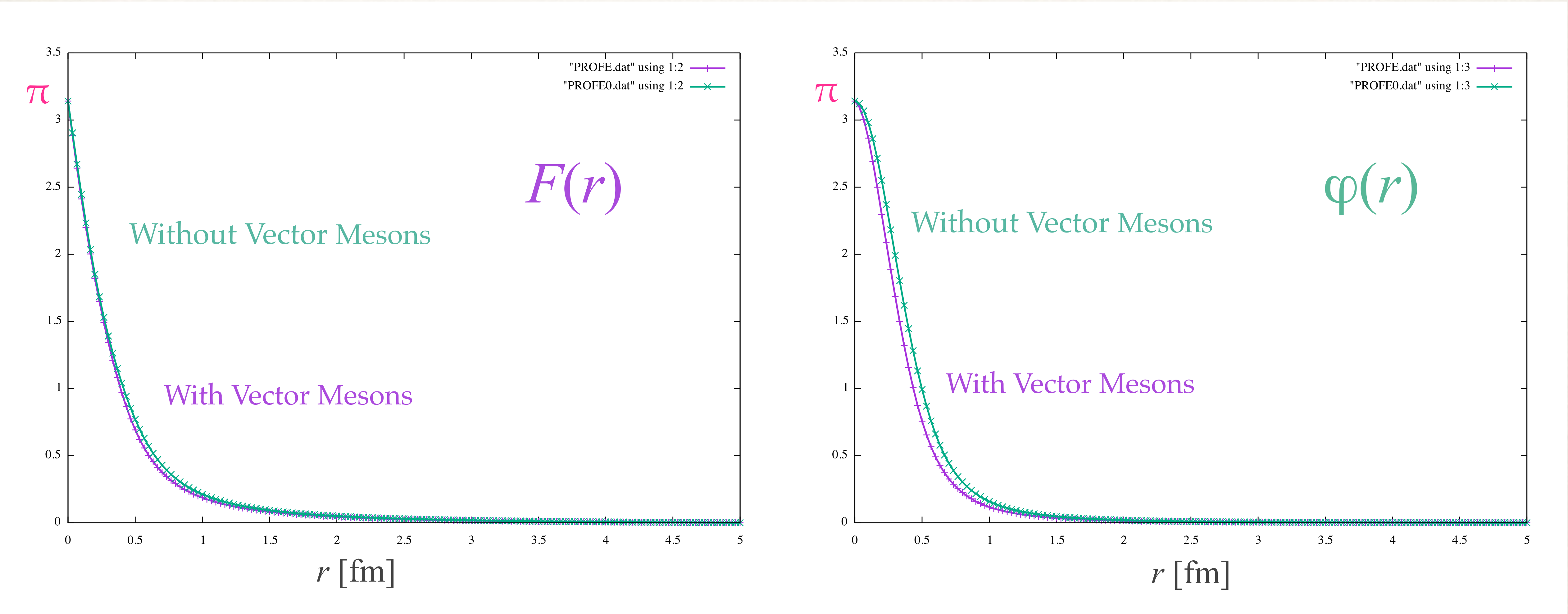
so, we find $M_{\rm H} \simeq 2.006\, M_{\rm B=1}$ (in chiral limit)

- With this result, we can see that the H-dibaryon mass is almost equal to two B=1 hedgehog baryon mass ($M_{\rm H} \simeq 2M_{\rm B=1}$).
- Then, H mass is expected to be smaller than two nucleon mass in the chiral limit:
  - In fact, nucleon (flavor-octet baryon) mass $M_{\rm N}$ is larger than hedgehog mass $M_{\rm B=1}$ by rotational energy:
    $M_{\rm N} = M_{\rm B=1}$ + (rotational energy) ($> M_{\rm B=1}$), and satisfies $M_{\rm H} < 2M_{\rm N}$.

(cf. In standard Skyrmion, rotational energy is estimated about 150MeV.)

Comparison to $G(r)$=0 Results

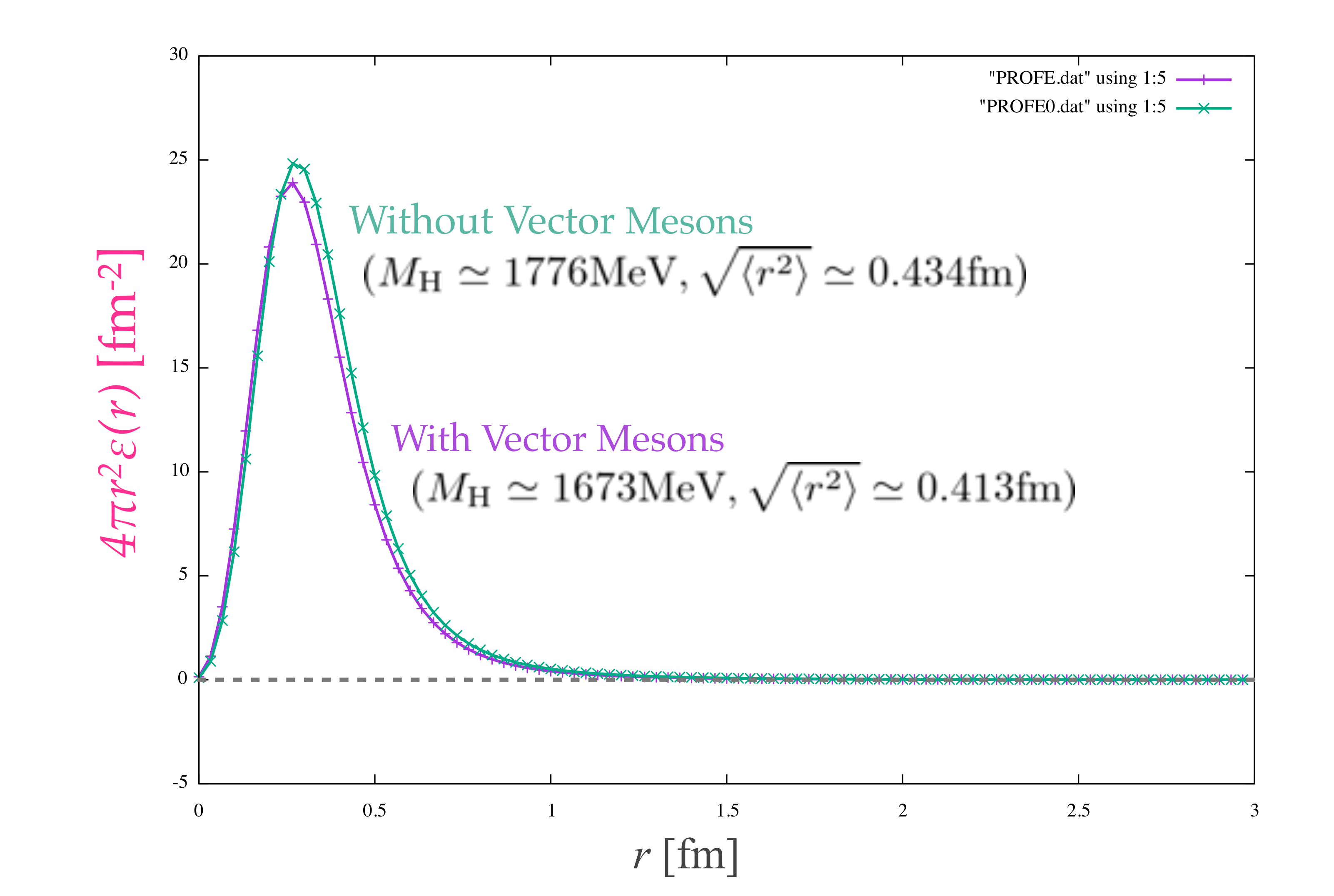
Vector Meson Effect for Chiral Functions $F(r)$, $\varphi(r)$ in H-dibaryon



- Chiral profiles F(r), $\varphi(r)$ are almost unchanged and shrink slightly by the vector-meson effect.

Comparison to $G(r)$=0 Results

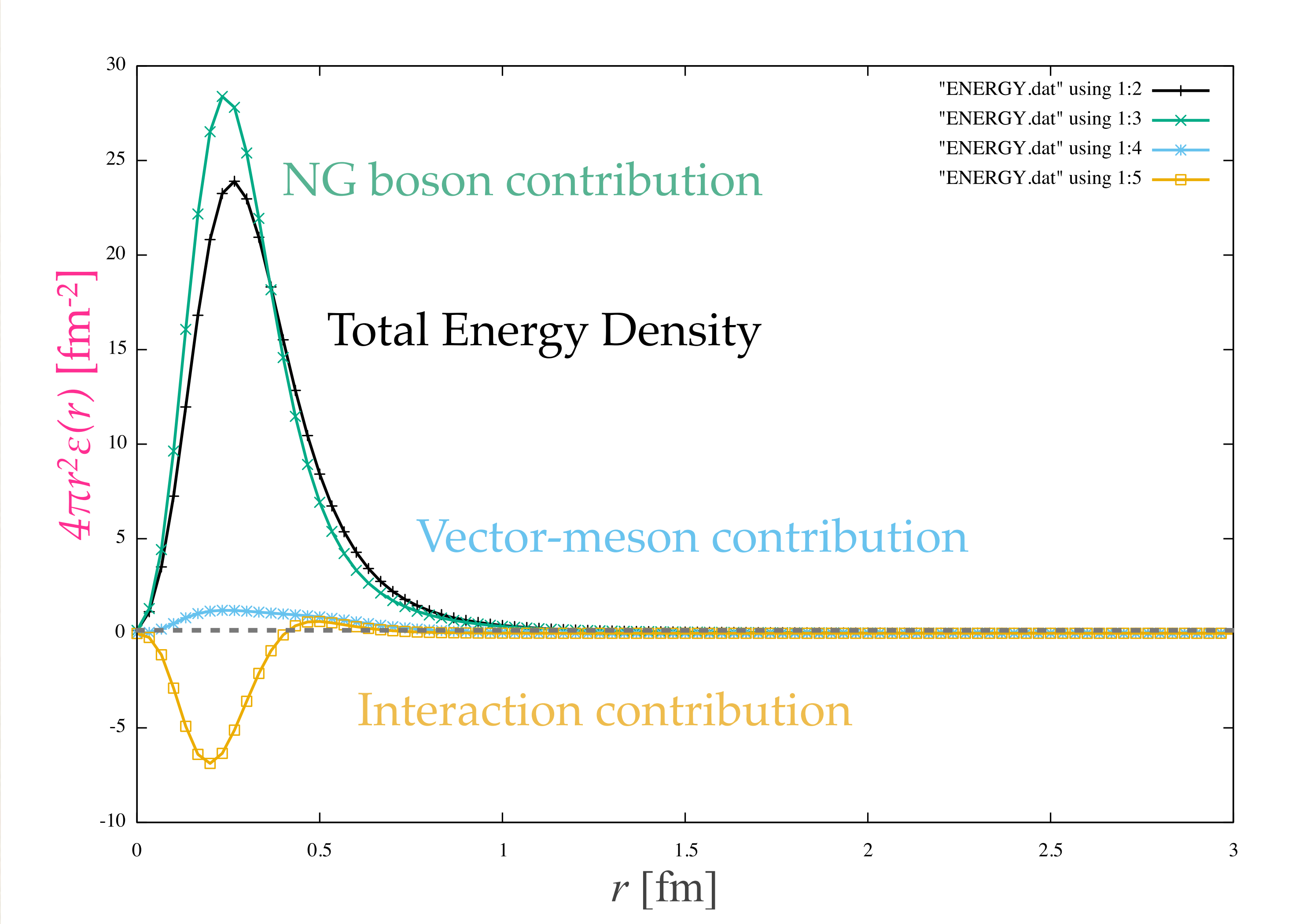
Vector Meson Effect to Energy Density in H-dibaryon



- The energy density also shrinks slightly by the vector meson effect.
- About 100MeV (6%) mass reduction is occurred by the vector meson effect.

Details of Energy Density

Each Contribution to Energy Density in H-dibaryon



Each Contribution to the Energy

Total Energy of Soliton H
1673MeV (100)

NG-boson Contribution
1795MeV (107.3)

Vector-meson Contribution
119MeV (7.1)

Interaction Contribution
-241MeV (-14.4)

- The H-dibaryon mass is lowered by the interaction between NG bosons and Vector mesons in the interior region of the H-dibaryon.

Contents

Summary

- We have formulated H-dibaryon (uuddss) in holographic QCD for the first time.
- We have investigated H-dibaryon as a soliton solution in holographic QCD, and have found that
  - the H-dibaryon mass is about 1.7GeV in the chiral limit, which can be smaller than the two nucleon mass.
  - chiral profile functions F(r), $\varphi(r)$ and energy density shrink slightly by the vector-meson effect.